Luis Alvarez 100th Birthday Symposium
University of California at Berkeley
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Hydrogen Bubble Chambers

Arthur H. Rosenfeld
Alvarez Group Member – 1955-1974

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Presentation available at www.ArtRosenfeld.org

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Nobel Prizes at Berkeley and LBNL, and **via** LBNL – Steven Chu's Count

- **Nobel Prizes closely related to Alvarez:**
  - You will hear from George Smoot and Saul Perlmutter

- **Statistics –** as of Perlmutter in 2011:
  - UC-Berkeley faculty: 22
    - Joint – UCB faculty/LBNL: 13 – large overlap
  - **LBNL graduate students or postdocs who subsequently received Nobel prize while working elsewhere: 30**

- Steven Chu knew, or read the biographies of, about 50 Nobel laureates and came up with this surprising extra 30 with a connection to LBNL

Discovering Alvarez

Selected Works of Luis W. Alvarez, with Commentary by His Students and Colleagues

EDITED BY

W. Peter Trower

RECENT DEVELOPMENTS IN PARTICLE PHYSICS

by

LUIS W. ALVAREZ

The Lawrence Radiation Laboratory Berkeley, California

Nobel Lecture, December 11, 1968

When I received my B. S. degree in 1932, only two of the fundamental particles of physics were known. Every bit of matter in the universe was thought to consist solely of protons and electrons. But in that same year, the number of particles was suddenly doubled. In two beautiful experiments, Chadwick showed that the neutron existed, (1) and Anderson photographed the first unmistakable positron track. (2) In the years since 1932, the list of known particles has increased rapidly, but not steadily. The growth has instead been concentrated into a series of spurts of activity.

Following the traditions of this occasion, my task this afternoon is to describe the latest of these periods of discovery, and to tell you of the development of the tools and techniques that made it possible. Most of us who become experimental physicists do so for two reasons; we love the tools of physics because to us they have intrinsic beauty, and we dream of finding new secrets of

Luis' Ambitious Vision – 1954

- Exploit three new technologies:
  - Bevatron at LBNL
  - Develop **hydrogen** bubble chambers
  - Use computers to interpret photographs of bubble chamber events – assigned to me
    - We still used 100 human scanners to recognize events
- What Luis considered visionary, I considered overwhelming – I needed a whole team, particularly Frank Solmitz

Lynn Stevenson, Frank Solmitz, Art Rosenfeld, Luis Alvarez, and Lina Galtieri

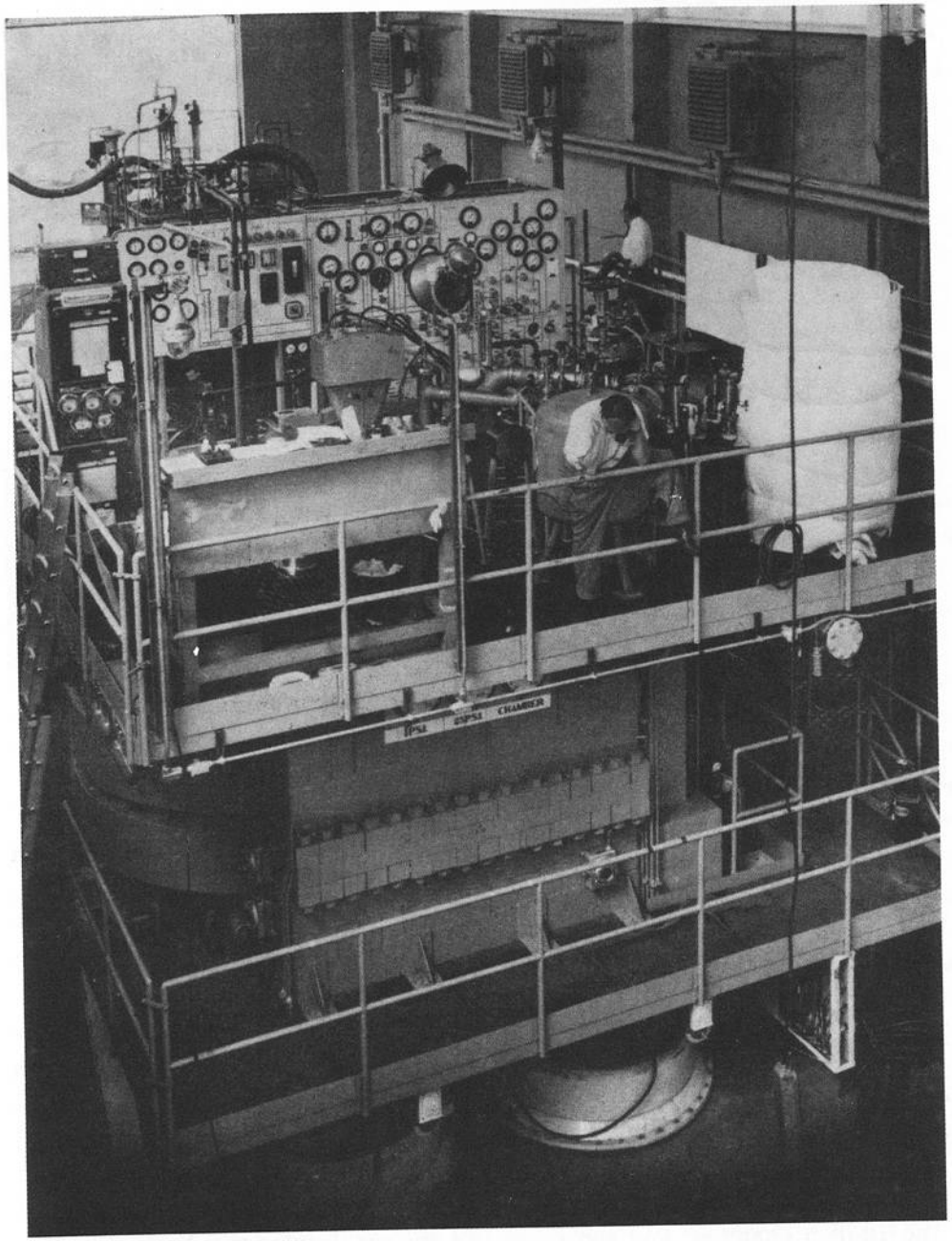
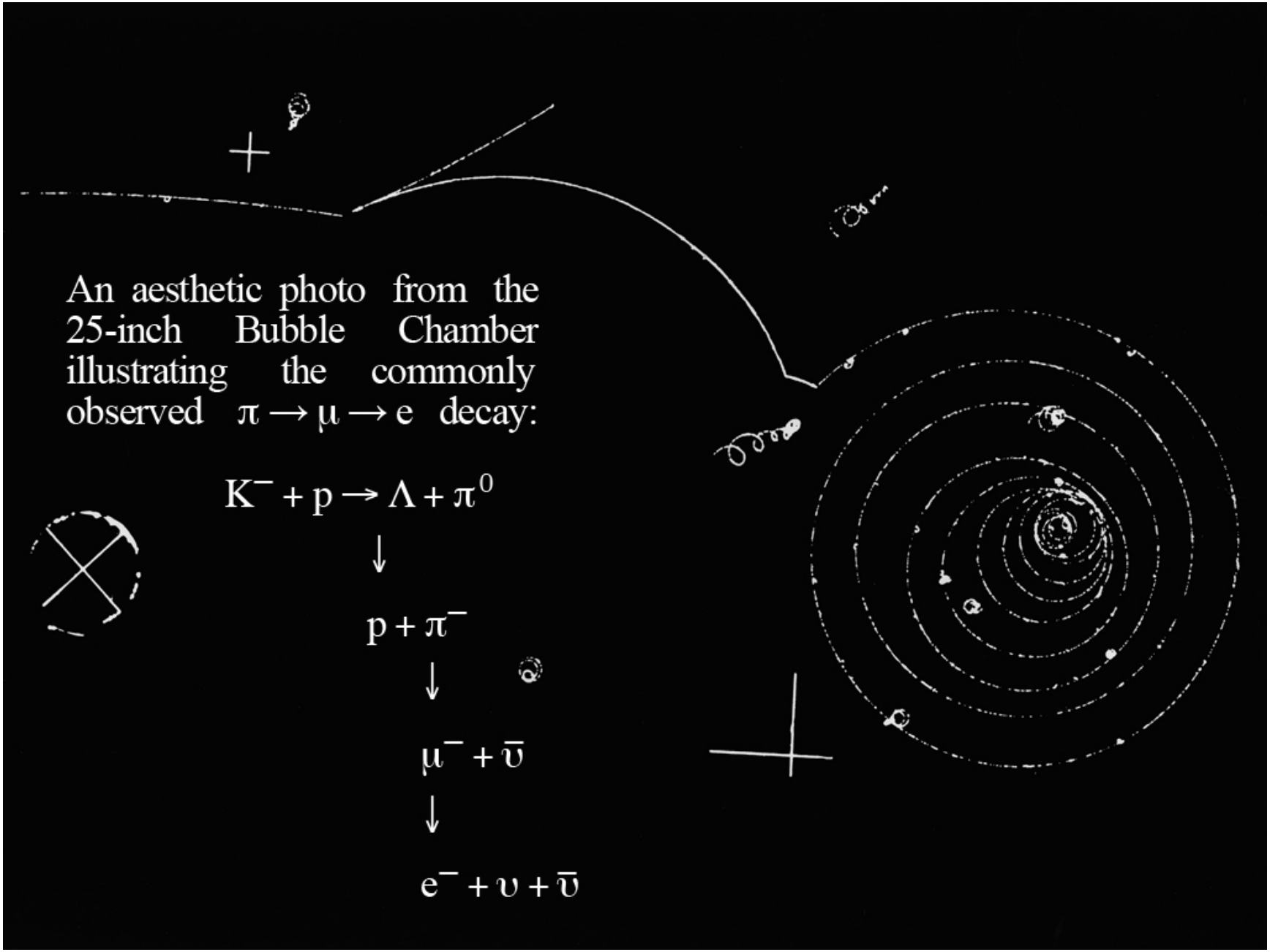


Fig. 7.
72 inch bubble chamber in its building.


An aesthetic photo from the 25-inch Bubble Chamber illustrating the commonly observed $\pi \rightarrow \mu \rightarrow e$ decay:
$K^- + p \rightarrow \Lambda + \pi^0$
$\downarrow$
$p + \pi^-$
$\downarrow$
$\mu^- + \bar{\upsilon}$
$\downarrow$
$e^- + \upsilon + \bar{\upsilon}$

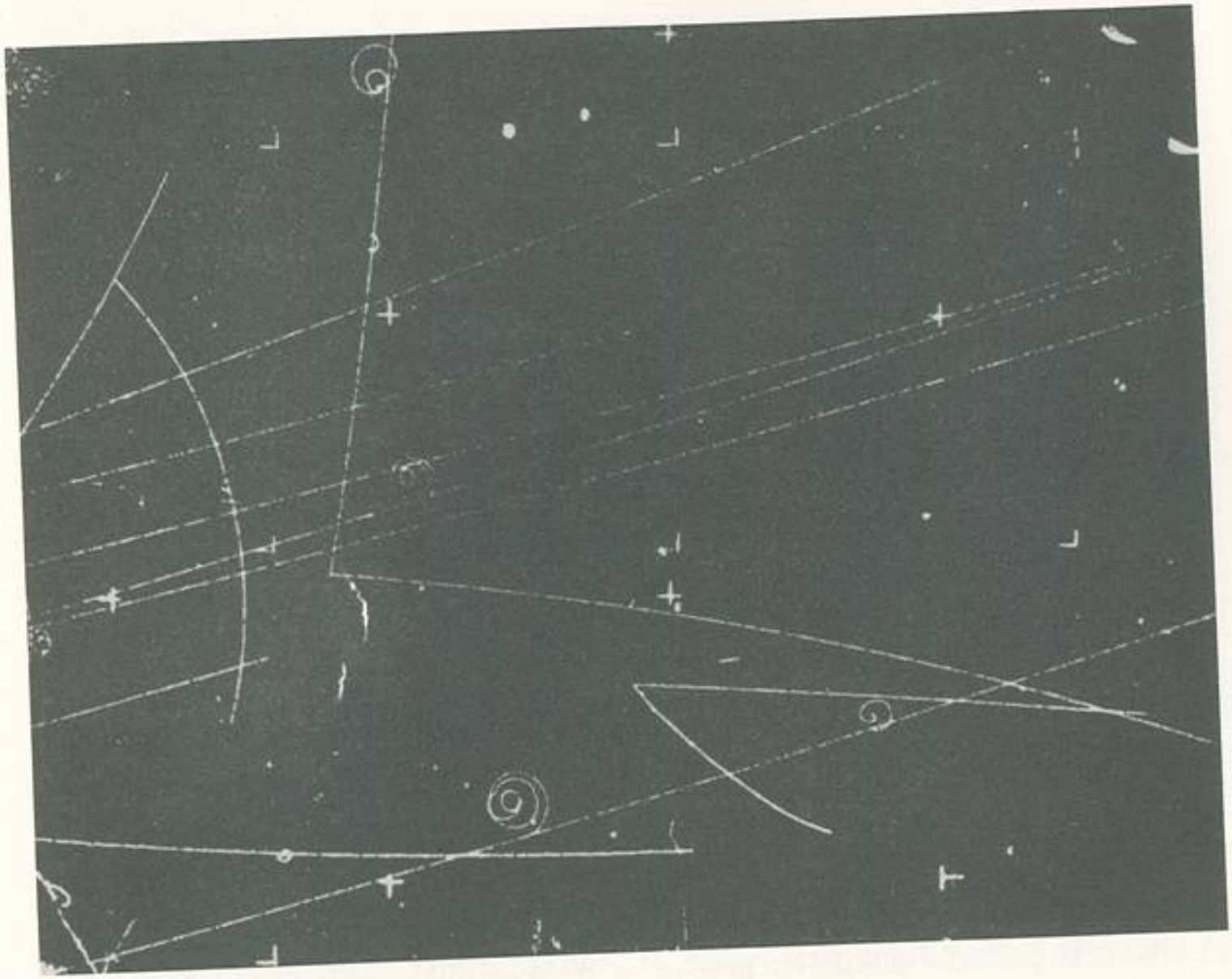
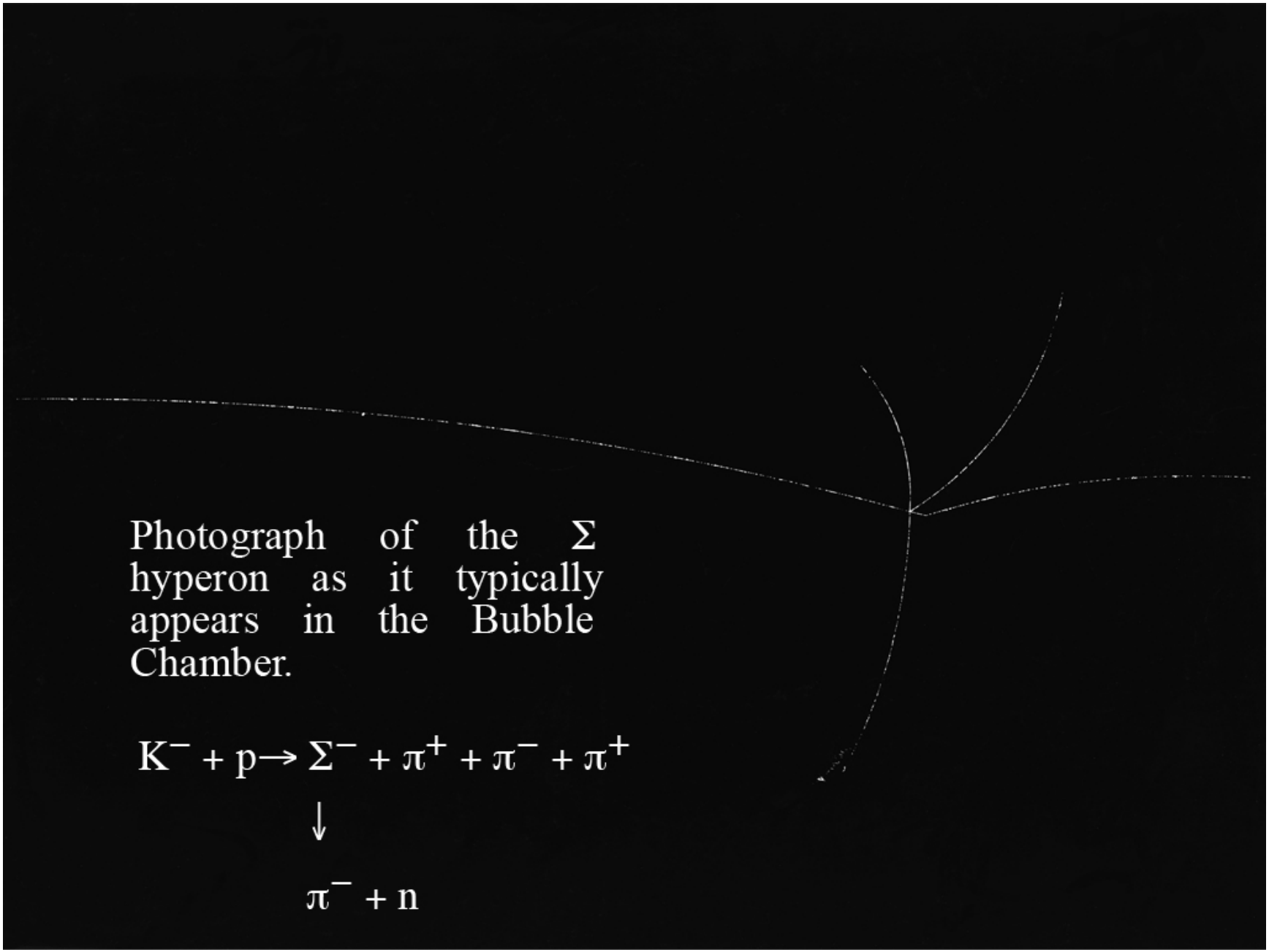


Fig. 1.
Caption: $\pi^- + p \rightarrow K^0 + \Lambda$.



Photograph of the Σ hyperon as it typically appears in the Bubble Chamber.

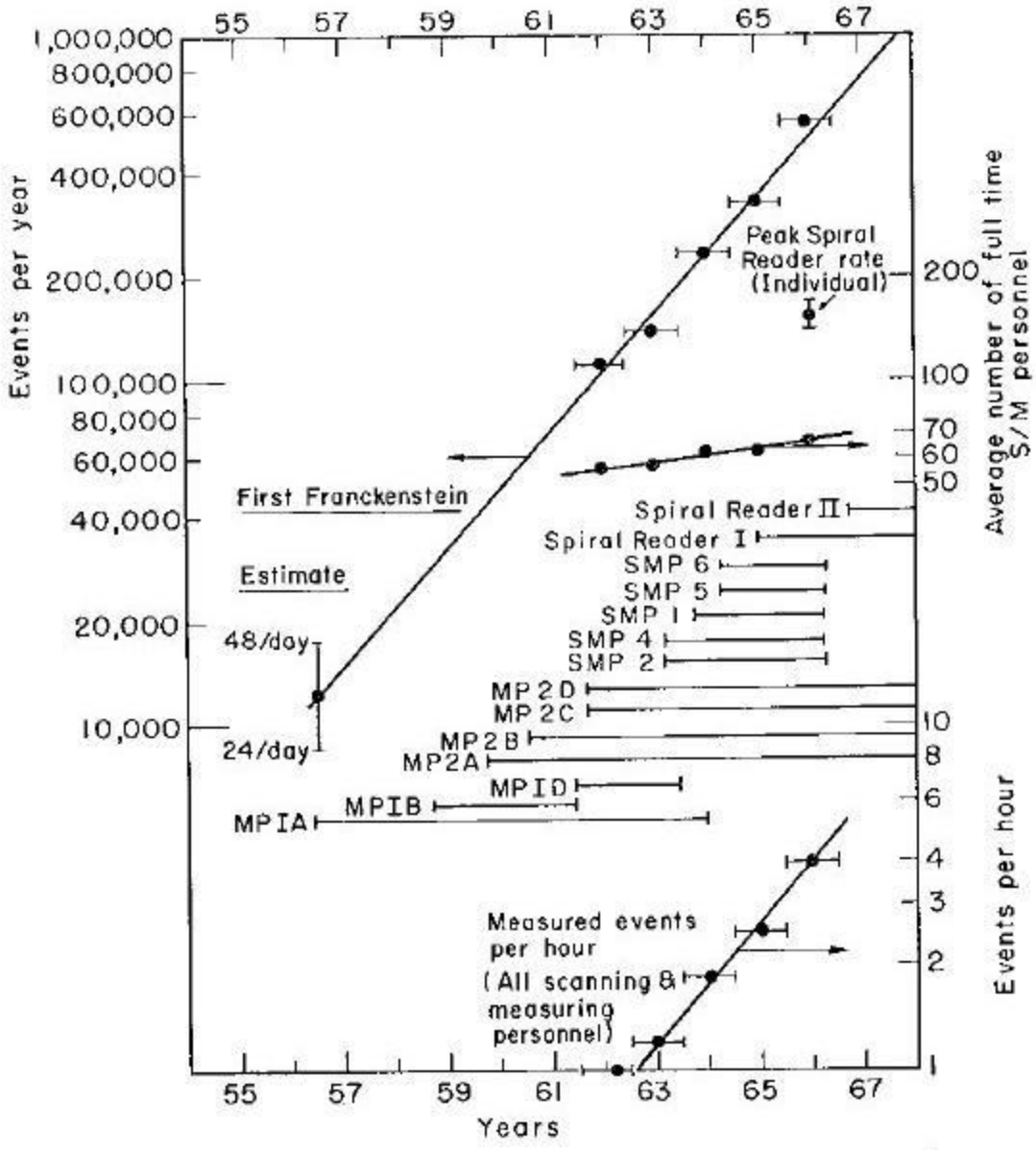
$$K^- + p \rightarrow \Sigma^- + \pi^+ + \pi^- + \pi^+$$

$$\downarrow$$

$$\pi^- + n$$

A Chain of Computer Programs

- Functions, program names, and people
  - Reconstruct tracks – PANG, Frank Solmitz, Horace Taft
  - Reconstruct vertices – GUTS & KICK, Art and Jim Snyder
  - Summarize results – EXAMINE & SUMX
  - Programming started in Assembly language and restarted in Fortran
- First use, 1957
  - Improved through 1968 (Alvarez Nobel Prize), managed to keep up with event rate (see next slide)


55
57
59
61
63
65
67
1,000,000
800,000
600,000
400,000
200,000
100,000
80,000
60,000
40,000
20,000
10,000
Events per year
Peak Spiral Reader rate (Individual)
200
100
70
60
50
Average number of full time S/M personnel
First Franckenstein
Estimate
48/day
24/day
Spiral Reader II
Spiral Reader I
SMP 6
SMP 5
SMP 1
SMP 4
SMP 2
MP2D
MP2C
MP2B
MP2A
MP1D
MP1B
MP1A
10
8
6
4
3
2
1
Events per hour
Measured events per hour (All scanning & measuring personnel)
Years

The International Particle Data Group

- Started in 1957 as UCRL 8030 with a “wallet card” (size of a modern credit card), authors Barkas and Rosenfeld
- Soon grew to a wallet sheet, then to particle data booklet, then to “Reviews of Modern Physics”
- Joint program of LBNL (Lina Galtieri) and CERN (Matts Roos). Currently Michael Barnett at LBNL.

See also the table of suggested $q\overline{q}$ quark-model assignments in the Quark Model section.

• Indicates particles that appear in the preceding Meson Summary Table. We do not regard the other entries as being established.

LIGHT UNFLAVORED ($S = C = B = 0$)

	$I^G(J^{PC})$		$I^G(J^{PC})$
• $\pi^\pm$	$1^-(0^-)$	• $\pi_2(1670)$	$1^-(2^{-+})$
• π^0	$1^-(0^{-+})$	• $\phi(1680)$	$0^-(1^{--})$
• η	$0^+(0^{-+})$	• $\rho_3(1690)$	$1^+(3^{--})$
• $f_0(600)$	$0^+(0^{++})$	• $\rho(1700)$	$1^+(1^{--})$
• $\rho(770)$	$1^+(1^{--})$	$a_2(1700)$	$1^-(2^{++})$
• $\omega(782)$	$0^-(1^{--})$	• $f_0(1710)$	$0^+(0^{++})$
• $\eta'(958)$	$0^+(0^{-+})$	$\eta(1760)$	$0^+(0^{-+})$
• $f_0(980)$	$0^+(0^{++})$	• $\pi(1800)$	$1^-(0^{-+})$
• $a_0(980)$	$1^-(0^{++})$	$f_2(1810)$	$0^+(2^{++})$
• $\phi(1020)$	$0^-(1^{--})$	• $X(1835)$	$?^?(?^{-+})$
• $h_1(1170)$	$0^-(1^{+-})$	• $\phi_3(1850)$	$0^-(3^{--})$
• $b_1(1235)$	$1^+(1^{+-})$	$\eta_2(1870)$	$0^+(2^{-+})$
• $a_1(1260)$	$1^-(1^{++})$	• $\pi_2(1880)$	$1^-(2^{-+})$
• $f_2(1270)$	$0^+(2^{++})$	$\rho(1900)$	$1^+(1^{--})$
• $f_1(1285)$	$0^+(1^{++})$	$f_2(1910)$	$0^+(2^{++})$
• $\eta(1295)$	$0^+(0^{-+})$	• $f_2(1950)$	$0^+(2^{++})$
• $\pi(1300)$	$1^-(0^{-+})$	$\rho_3(1990)$	$1^+(3^{--})$
• $a_2(1320)$	$1^-(2^{++})$	• $f_2(2010)$	$0^+(2^{++})$
• $f_0(1370)$	$0^+(0^{++})$	$f_0(2020)$	$0^+(0^{++})$
$h_1(1380)$	$?^-(1^{+-})$	• $a_4(2040)$	$1^-(4^{++})$
• $\pi_1(1400)$	$1^-(1^{-+})$	• $f_4(2050)$	$0^+(4^{++})$
• $\eta(1405)$	$0^+(0^{-+})$	$\pi_2(2100)$	$1^-(2^{-+})$
• $f_1(1420)$	$0^+(1^{++})$	$f_0(2100)$	$0^+(0^{++})$
• $\omega(1420)$	$0^-(1^{--})$	$f_2(2150)$	$0^+(2^{++})$
• $f(1430)$	$0^+(2^{++})$	$\rho(2150)$	$1^+(1^{--})$

STRANGE ($S = \pm1$, $C = B = 0$)

	$I(J^P)$
• $K^\pm$	$1/2(0^-)$
• K^0	$1/2(0^-)$
• K^0_S	$1/2(0^-)$
• K^0_L	$1/2(0^-)$
$K^*_0(800)$	$1/2(0^+)$
• $K^*(892)$	$1/2(1^-)$
• $K_1(1270)$	$1/2(1^+)$
• $K_1(1400)$	$1/2(1^+)$
• $K^*(1410)$	$1/2(1^-)$
• $K^*_0(1430)$	$1/2(0^+)$
• $K^*_2(1430)$	$1/2(2^+)$
$K(1460)$	$1/2(0^-)$
$K_2(1580)$	$1/2(2^-)$
$K(1630)$	$1/2(?^?)$
$K_1(1650)$	$1/2(1^+)$
• $K^*(1680)$	$1/2(1^-)$
• $K_2(1770)$	$1/2(2^-)$
• $K^*_3(1780)$	$1/2(3^-)$
• $K_2(1820)$	$1/2(2^-)$
$K(1830)$	$1/2(0^-)$
$K^*_0(1950)$	$1/2(0^+)$
$K^*_2(1980)$	$1/2(2^+)$
• $K^*_4(2045)$	$1/2(4^+)$
$K_2(2250)$	$1/2(2^-)$

CHARMED, STRANGE ($C = S = \pm1$)

	$I(J^P)$
• $D^\pm_s$	$0(0^-)$
• $D^{*\pm}_s$	$0(?^?)$
• $D^*_{s0}(2317)^\pm$	$0(0^+)$
• $D_{s1}(2460)^\pm$	$0(1^+)$
• $D_{s1}(2536)^\pm$	$0(1^+)$
• $D_{s2}(2573)$	$0(?^?)$
$D^*_{s1}(2700)^\pm$	$0(1^-)$
$D^*_{sJ}(2860)^\pm$	$0(?^?)$
$D_{sJ}(3040)^\pm$	$0(?^?)$

BOTTOM ($B = \pm1$)

• $B^\pm$	$1/2(0^-)$
• B^0	$1/2(0^-)$
• $B^\pm/B^0$ ADMIXTURE	
• $B^\pm/B^0/B^0_s/b$-baryon ADMIXTURE	
V_{cb} and V_{ub} CKM Matrix Elements	
• B^*	$1/2(1^-)$
$B^*_J(5732)$	$?(?^?)$
• $B_1(5721)^0$	$1/2(1^+)$
• $B^*_2(5747)^0$	$1/2(2^+)$

BOTTOM, STRANGE ($B = \pm1$, $S = \mp1$)

$c\overline{c}$

	$I^G(J^{PC})$
• $\eta_c(1S)$	$0^+(0^{-+})$
• $J/\psi(1S)$	$0^-(1^{--})$
• $\chi_{c0}(1P)$	$0^+(0^{++})$
• $\chi_{c1}(1P)$	$0^+(1^{++})$
• $h_c(1P)$	$?^?(1^{+-})$
• $\chi_{c2}(1P)$	$0^+(2^{++})$
• $\eta_c(2S)$	$0^+(0^{-+})$
• $\psi(2S)$	$0^-(1^{--})$
• $\psi(3770)$	$0^-(1^{--})$
• $X(3872)$	$0^?(?^{?+})$
$X(3915)$	$0^+(?^{?+})$
• $\chi_{c2}(2P)$	$0^+(2^{++})$
$X(3940)$	$?^?(?^{??})$
• $\psi(4040)$	$0^-(1^{--})$
$X(4050)^\pm$	$?(?^?)$
$X(4140)$	$0^+(?^{?+})$
• $\psi(4160)$	$0^-(1^{--})$
$X(4160)$	$?^?(?^{??})$
$X(4250)^\pm$	$?(?^?)$
• $X(4260)$	$?^?(1^{--})$
$X(4350)$	$0^+(?^{?+})$
$X(4360)$	$?^?(1^{--})$
• $\psi(4415)$	$0^-(1^{--})$
$X(4430)^\pm$	$?(?^?)$
$X(4660)$	$?^?(1^{--})$

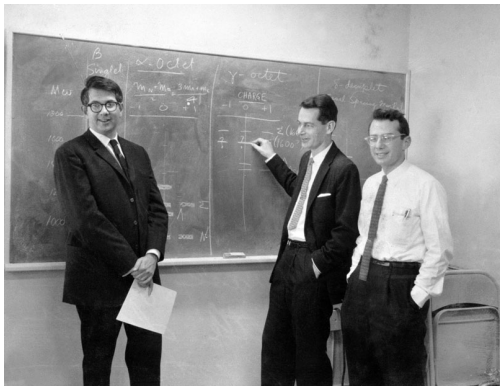
50th Anniversary

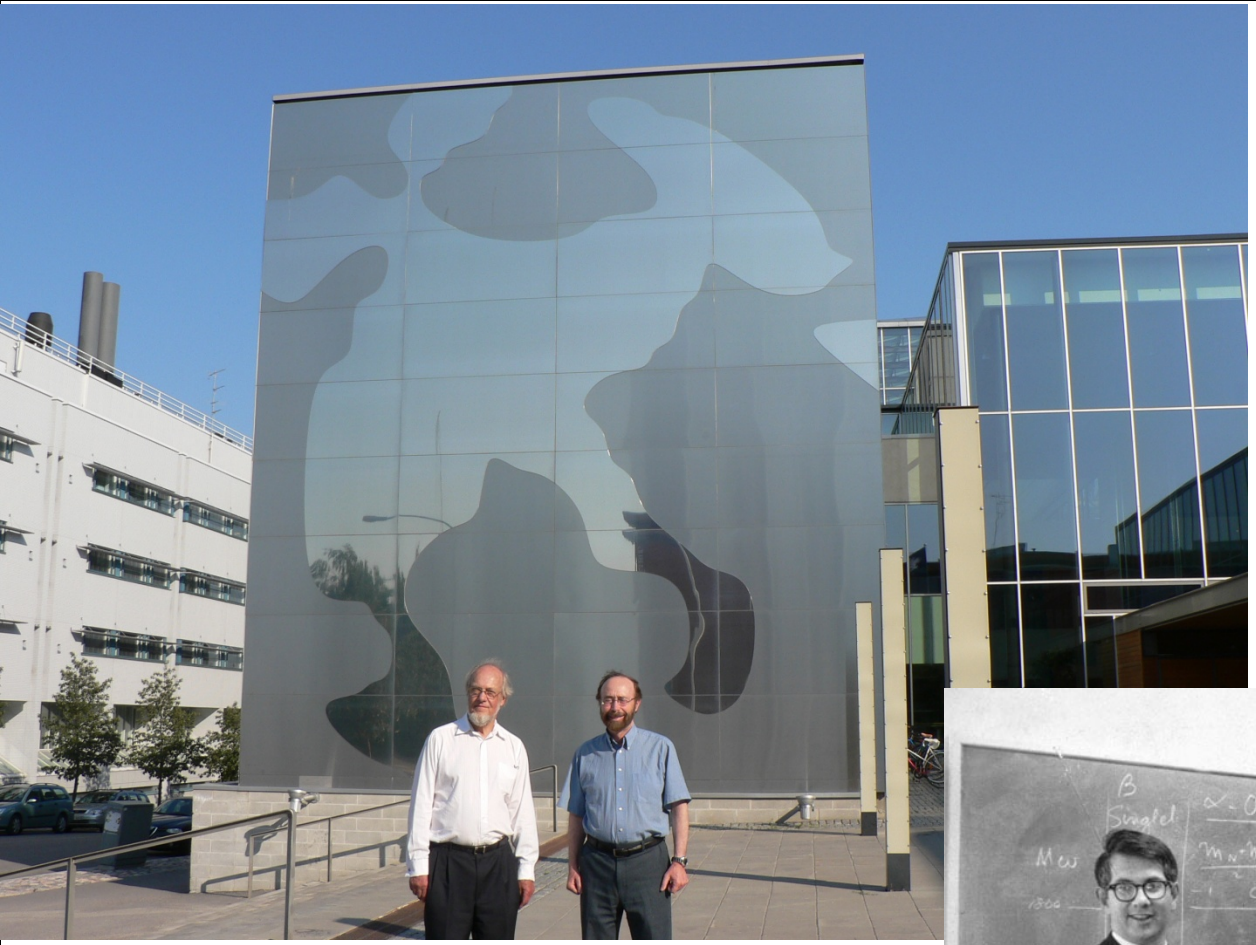
of the Particle Data Group

Also celebrating the

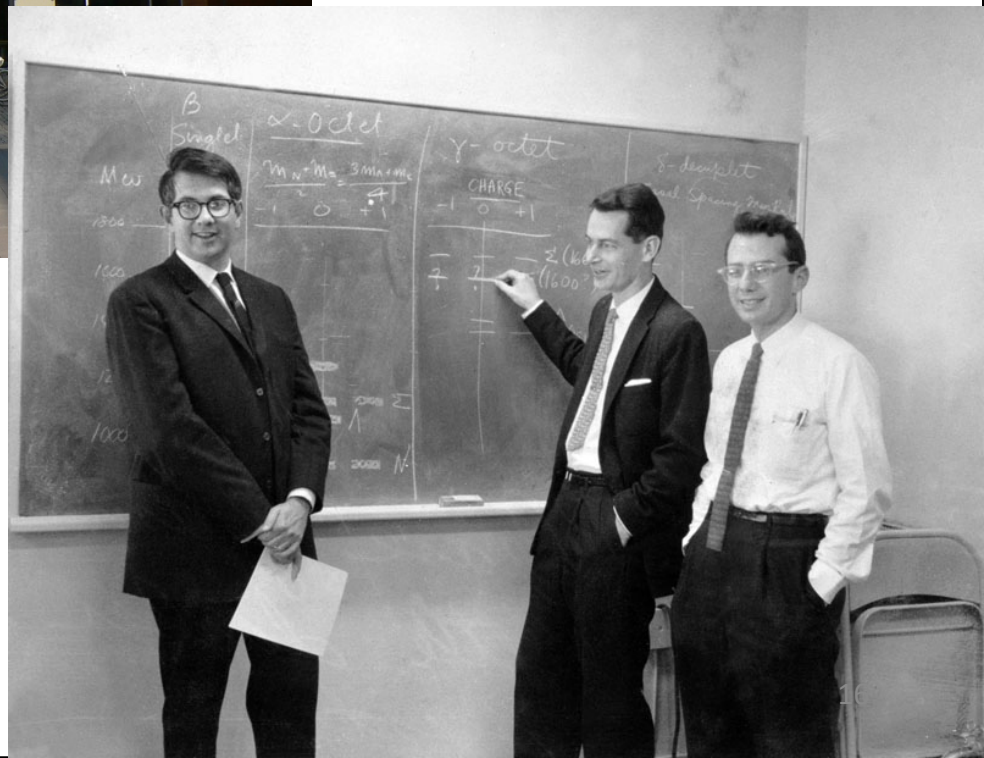
75th Birthday of Matts Roos

80th Birthday of Art Rosenfeld





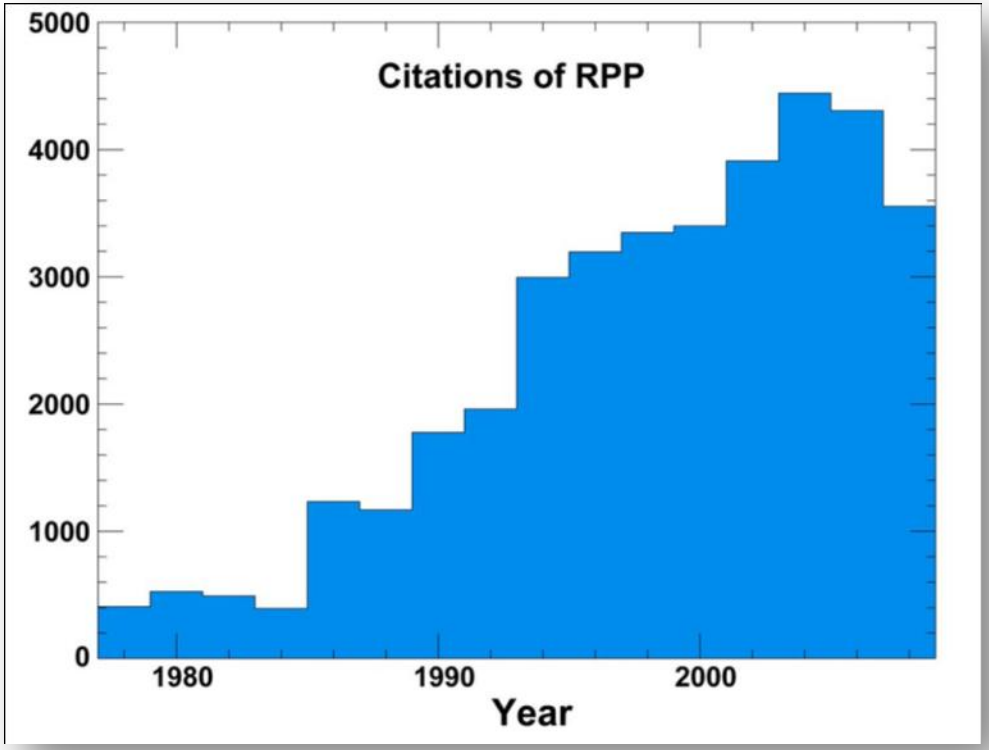
Matts Roos
Michael Barnett



Sheldon Glashow*
George Kalbfleisch
Art Rosenfeld

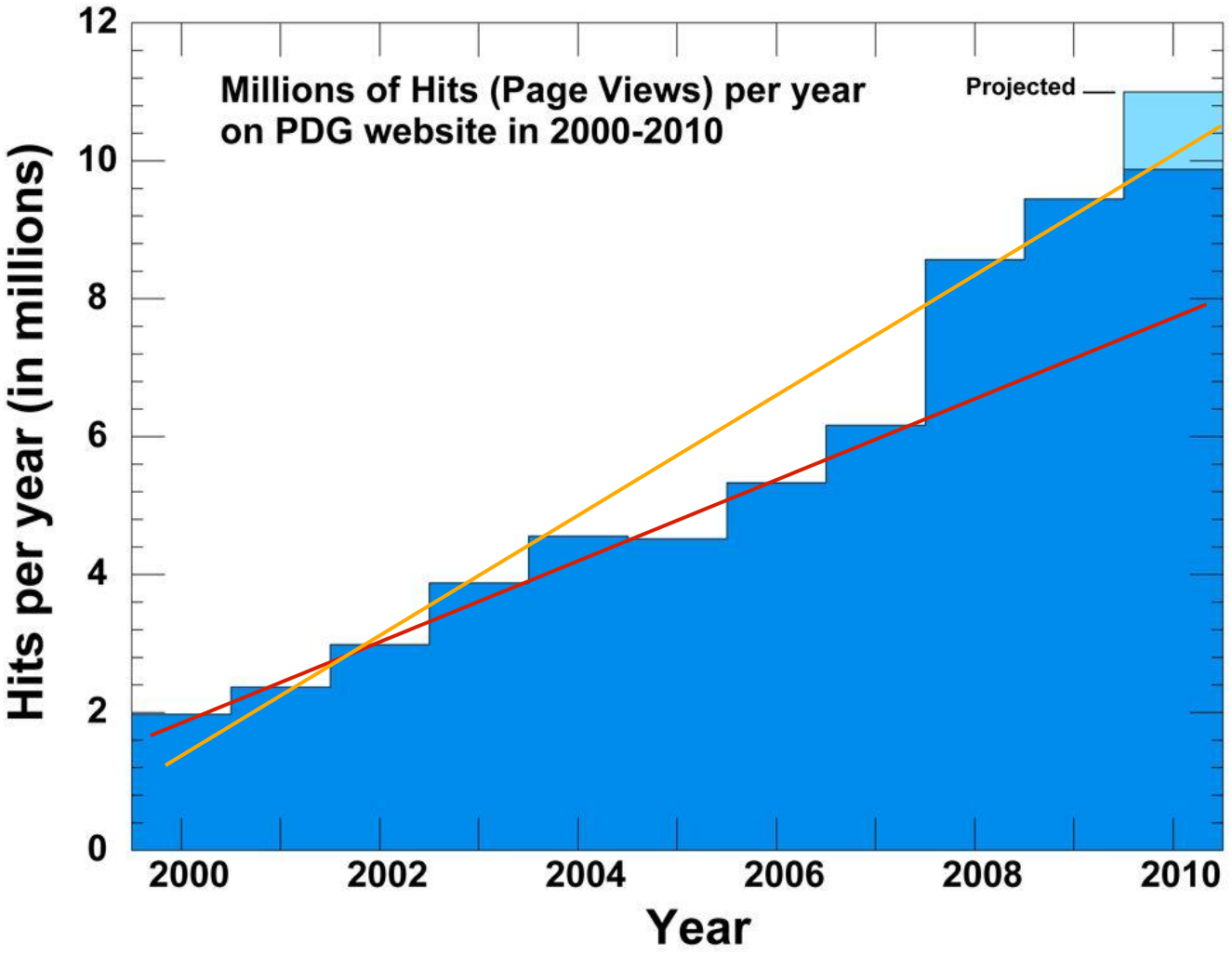
Top Cited

The Review is the all-time top cited article in High Energy Physics with 38,000 citations (SLAC-SPIRES)



Major Web Presence

Excluding
Mirror sites
and
Education
webpages



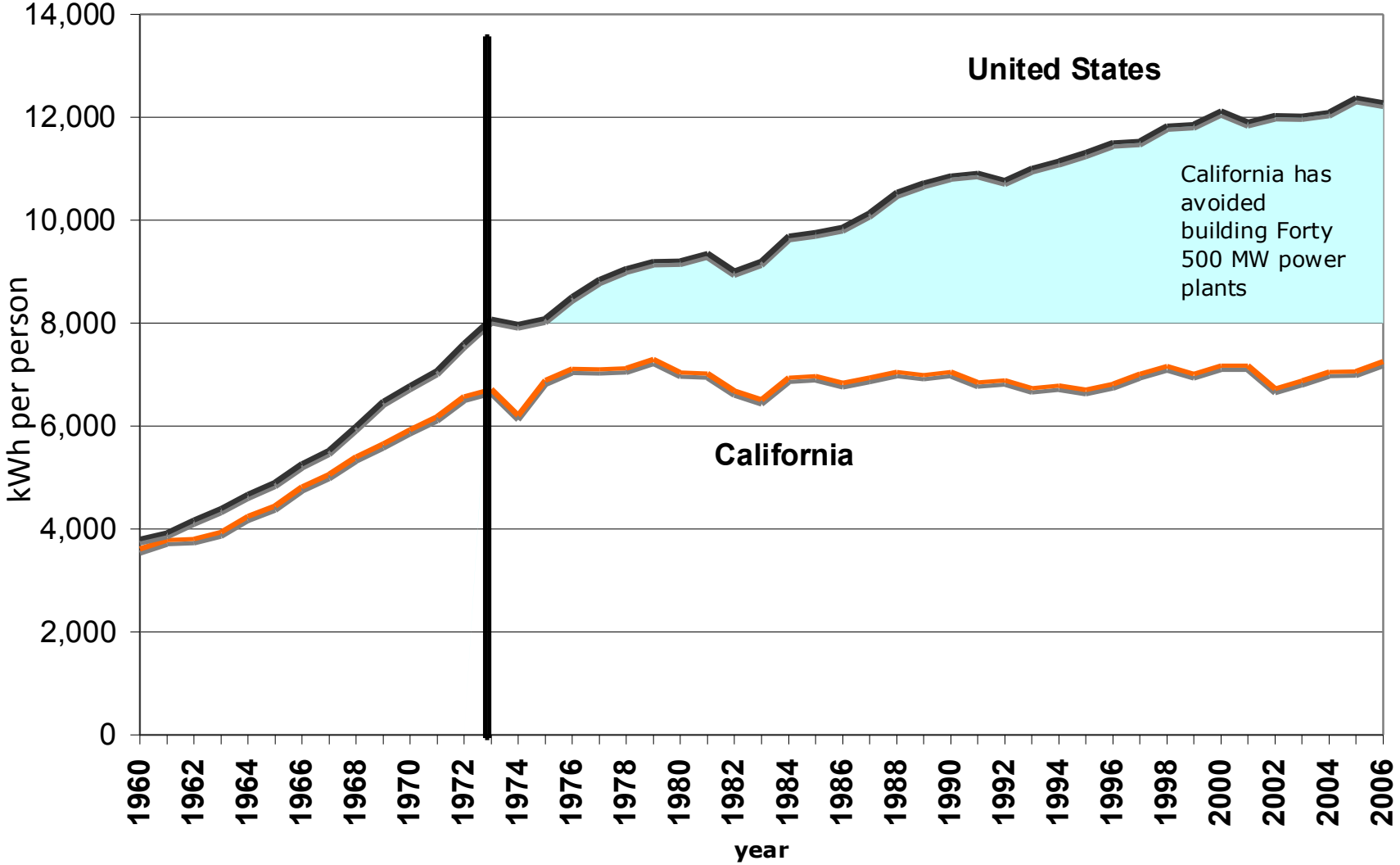
1973 Started Second Career

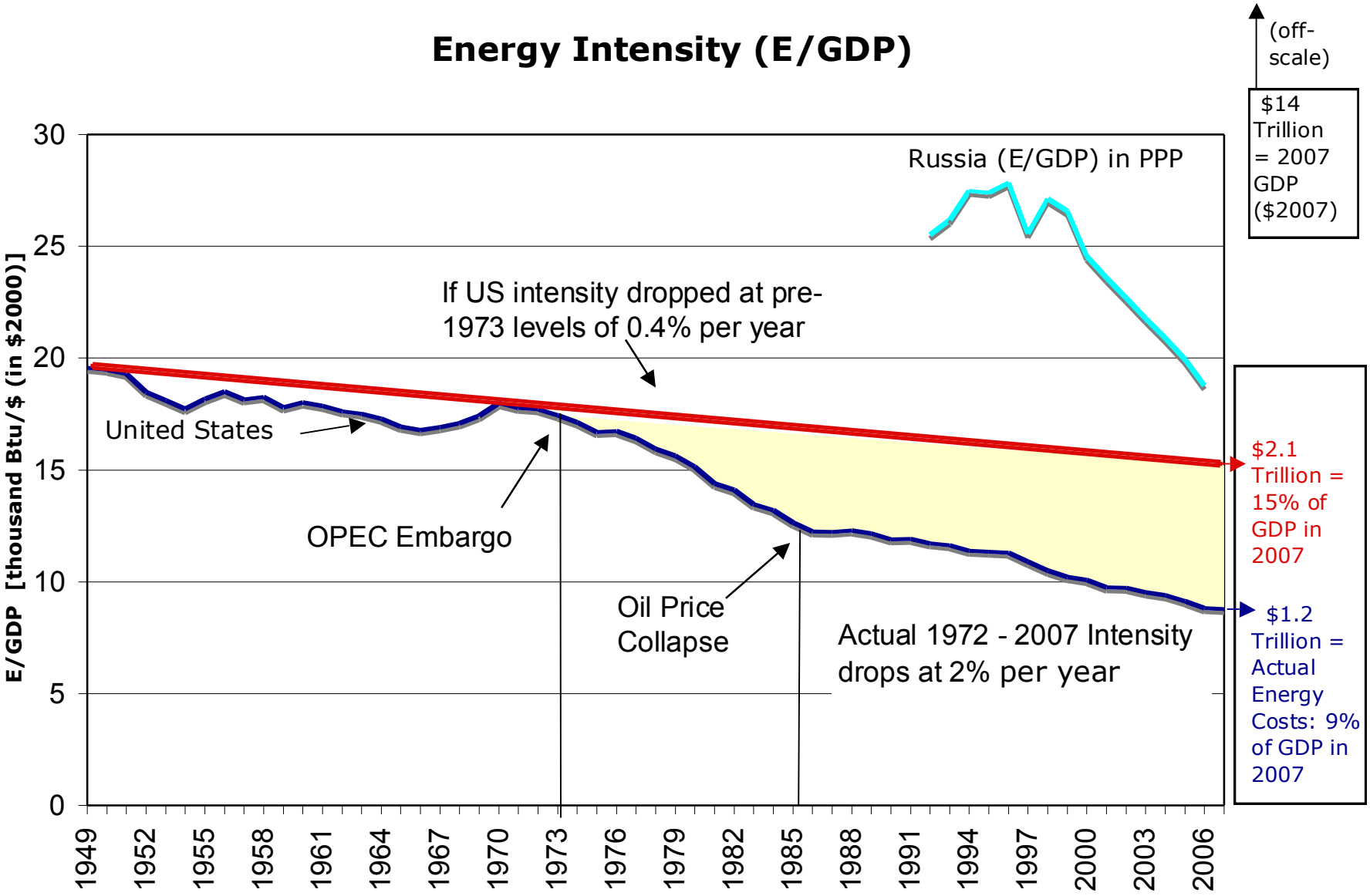
- 1973: OPEC oil embargo
- Long lines for gasoline
- New U.S. cars 14 mpg, new European cars 28 mpg, Japanese even more
- Same ratio for building energy “intensity”
- Fuel was dirt cheap and was treated like dirt

Second Career (cont'd)

- I decided to form an Energy Efficient Buildings program at LBNL, and took a "temporary" leave from particle physics
  - Strongly supported by Luis
- We developed better, more compact fluorescent lamps, "heat mirror" windows, computer programs to design efficient buildings, building and appliance standards, etc.
- "Temporary" became permanent

Per capita electricity consumption




Energy Intensity (E/GDP)
E/GDP [thousand Btu/$ (in $2000)]
30
25
20
15
10
5
0
1949
1952
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
Russia (E/GDP) in PPP
(off-scale)
$14 Trillion = 2007 GDP ($2007)
If US intensity dropped at pre-1973 levels of 0.4% per year
United States
OPEC Embargo
Oil Price Collapse
Actual 1972 - 2007 Intensity drops at 2% per year
$2.1 Trillion = 15% of GDP in 2007
$1.2 Trillion = Actual Energy Costs: 9% of GDP in 2007